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LIKELIHOOD FUNCTION ESTIMATION (LIFE) MODEL: UTILITY IN THE DEV--ETC(U)

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**LIKELIHOOD FUNCTION ESTIMATION (LIFE) MODEL:
UTILITY IN THE DEVELOPMENT OF AN
ENLISTMENT STANDARD**

By

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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SUMMARY

The objectives of the current study were: (a) to present the preliminary results of Project IMAGE using the prototype Likelihood Function Estimation (LIFE) Model to develop an enlistment standard and (b) to compare the utility of the prototype versus the enhanced LIFE Model for predicting first-term airman success.

Any enlistment standard will have two errors associated with it. It will allow enlistment to some applicants who will later fail, and it will also deny enlistment to others who would have otherwise succeeded.

These two errors are inextricably associated with maintaining the quality and quantity of recruits. Because recruiting has become increasingly difficult with the adoption of the all-volunteer force, the Air Force directed a research effort to improve existing enlistment criteria aimed at reducing these errors.

The revised enlistment standard which used the prototype LIFE Model was evaluated by tracking accessions allowed to enlist under Project IMAGE through Basic Military Training and Technical Training. To increase the effectiveness and flexibility of the prototype LIFE model, several modifications were made. The enhanced model was then used to develop a new equation which could be used in the Procurement Management Information System as a new enlistment standard upon the completion of project IMAGE.

The enlistment standard implemented under Project IMAGE was tested during the period 1 October 1978 to 31 May 1979. During this period, IMAGE allowed 3,911 recruits to enter the Air Force who would not have otherwise been qualified. These recruits represented a 6% increase in the number of non-prior service accessions. The attrition loss rate for the first year was 8.9% for the IMAGE accessions, which compared favorably to the 8.8% attrition rate of the control group which entered under the traditional Air Force enlistment standard.

Several modifications were made to the prototype LIFE model to enhance its research value. A new iterative method of maximization was incorporated which eliminated most of the data handling problems, and decreased computer run time by over 400%. In addition, more statistical inference capability was added, and the algorithm was documented to facilitate conversion to other computer systems and to give more widespread availability to other users.

A new predictive equation was developed using the enhanced LIFE model for predicting first-term success. This equation was developed using a 1975 airman accession data base and was then compared to the prototype equation used in Project IMAGE. The new predictive equation included more variables and, when cross-validated in the 1975, data base, was better able to predict success than the IMAGE equation.

1. Project IMAGE has successfully demonstrated that the goal of increased accessions without increased attrition is achievable, using the prototype LIFE model equation.

2. The enhanced LIFE model prediction equation was capable of more reliable predictions of first term success than was the Project IMAGE equation.

PREFACE

The Likelihood Function Estimation (LIFE) Model is an enhanced version of the Motivation Attrition Prediction (MAP) Model, developed by the Air Force Manpower and Personnel Center (AFMPC). AFMPC developed this prototype model during the period 1975-1977 and has applied this work as a test for Air Force enlistment standards. The research reported herein was accomplished under work unit 20770413 and was a combination of contract and in-house research. This research is in support of the Enlisted Force Acquisition and Distribution System (EFADS-1) thrust of this Laboratory. With this model, the Laboratory will be able to better model attrition behavior which will allow researchers to use attrition prediction as an integral part of any classification and assignment system. Valuable inputs to this effort were made by various members of AFMPC, including Captain Tom Curry and Colonel Frank Rorscher. The in-house enhancement of the model was done by Major Ed Reeves, Chief of the Decision Models Function of the Manpower and Personnel Division.

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LIKELIHOOD FUNCTION ESTIMATION (LIFE) MODEL:
UTILITY IN THE DEVELOPMENT OF AN ENLISTMENT STANDARD

I. INTRODUCTION

Enlistment standards are the mechanism through which the Air Force personnel planners control the quantity and quality of recruits. These mental and physical standards are designed (a) to permit adequate numbers of applicants to meet Air Force manning requirements and (b) to maximize the aggregate quality of the first-term airman force in terms of mental and physical attributes. Unfortunately long-range prediction of human behavior is difficult; consequently, enlistment standards generate two types of errors. First, they allow enlistment to some applicants who will be unsuccessful in the Air Force. Second, they deny enlistment to some who would have otherwise succeeded.

With the adoption of the All-Volunteer Force, the Air Force started a research effort to improve the methodologies by which post-enlistment behavior could be predicted. To meet this need, the Likelihood Function Estimation (LIFE) Model was designed and developed (Dempsey, Sellman, & Fast, 1979). This prototype version was intended to assess the feasibility of this model. This feasibility is currently being tested in an official Air Force test, known as Project Improved Minimum Airmen Guidelines for Enlistment (IMAGE). Concurrently, a development effort was undertaken at the Air Force Human Resources Laboratory (AFHRL) to enhance the prototype version.

The objectives of this study were (a) to present the preliminary results of Project IMAGE using the prototype LIFE model to develop an enlistment standard and (b) to compare the utility of the prototype LIFE model versus the enhanced LIFE model for predicting first term airman success.

II. Assessment of Project IMAGE

With the advent of the All Volunteer Force in 1973, the Air Force experienced good recruiting years. This good market caused Air Force managers to raise enlistment standards, so that only the most qualified would be allowed to enlist. The enlistment standard used the four composites from the Armed Services Vocational Aptitude Battery (ASVAB), combined with the educational level of the applicant. As a minimum, the applicant must have achieved a score of 45 on the General aptitude composite and a total score of 170 on all four composites. In addition, the Air Force attempted to limit the number of non-high school graduates by applying more stringent mental standards (as measured by the Air Force Qualification Test [AFQT] composite of the ASVAB). This resulted in a higher percentage of high school graduates among the recruit population. This combination of enlistment standards in general raised the quality of Air Force recruits, but at the expense of turning away many otherwise qualified applicants. When the more austere recruiting years arrived in the late seventies, the Air Force was faced with not being able to maintain the desired force level and their high enlistment standards.

The application of the prototype LIFE model to predict attrition was brought to the attention of Air Force managers, and a plan to test it as an alternate enlistment standard was developed. The test was named Project IMAGE and, under the plan, the equation developed for the demonstration was to be used to waiver individuals into the Air Force. An individual who passed all enlistment standards, except the ASVAB General 45, composite 170 standard, would be further processed through the IMAGE equation. If this equation predicted the applicant would be successful in the first term, that individual would be allowed to enlist and would be assigned individually to a particular Air Force Specialty Code (AFSC). Each record of an individual who was

allowed to enlist with an IMAGE waiver was flagged so that the IMAGE enlistees could be followed through training and into the operational Air Force. The Air Force Manpower and Personnel Center (AFMPC) required quarterly updates on the attrition rates of the IMAGE enlistees and comparisons with the other categories of recruits.

Test Results

The Project IMAGE test was started 1 October 1978 and was completed on 31 May 1979. During this period 3,911 people were waived into the Air Force under Project IMAGE. By comparison 62,704 individuals enlisted in the Air Force during this same time period who passed the General 45, composite 170 standard, and educational qualification. These two groups will be tracked for 4 years (through the first term) and results reported at that time; however, it is worthwhile to discuss the preliminary results of the test through 30 September 1979. The analysis focused on the attrition experience of the two groups of recruits (pass G45, C170, and fail G45, C170) even though some of this group had just completed basic training and others had been in the field for 6 months or more. It should be noted that results of the analysis show only general trends and should not be interpreted as a comprehensive evaluation of the IMAGE equation as an enlistment standard. In addition, since IMAGE people were allowed to enter only selected, hard-to-fill AFSCs (with high attrition), the follow-on analysis will compare IMAGE versus non-IMAGE people, after adjusting for the differences in AFSC attrition rates. The current analysis, however, was not broken out by AFSC, and may not reflect the actual utility of the IMAGE equation.

Table 1 shows general characteristics of the IMAGE enlistees. The important features are that only two were non-high school graduates and the vast majority were measured as mental category III-B by the AFQT composite. Table 2 shows the same characteristics for the other group of recruits who passed the G45, C170 standard. In this group, the

18.1% (12.9% + 5.2% from Table 2 "Total" column) who failed to graduate from high school were fairly evenly divided between mental categories II, III-A, and III-B. Table 3 contains the FY79 attrition analysis for the two groups of recruits. Overall, the IMAGE attrition rate of 8.9% is not significantly different from the current standard group attrition rate of 8.8%. The male IMAGE group has attrited at a slightly higher rate through Basic Military Training (BMT) and Technical Training (TT). The female attrition rate for the IMAGE group for both BMT and TT was much higher than female current standard accessions; however, due to the small number of women, valid comparisons are difficult to make. Although females overall attrit at a higher rate (see Table 3), the effect of these differences is absent in the total sample because the IMAGE group is predominantly male (96.7% see Table 1). The limit on the number of females in the IMAGE sample was a result of Project IMAGE policy which allowed IMAGE females to enlist only in hard-to-fill, non-traditional jobs which require high scores on the mechanical and electronics composites of ASVAB.

The IMAGE equation did fulfill its promise of increasing Air Force accessions by 6% without increasing attrition. Based on the promising results obtained through September 1979, the Air Force Deputy Chief of Staff for Manpower and Personnel (AF/MP) declared the IMAGE test successful and ordered the test of the IMAGE waiver to be continued as part of the enlistment process. For operational use, IMAGE qualified personnel will be allowed to enlist in any Air Force job for which they qualify, and it will be done in the Procurement Management Information System (PROMIS), rather than individually.

Table 1. Characteristics of IMAGE Enlistments
(Pass IMAGE - Fail Current Standard)

	Male		Female		Total	
	Number	%	Number	%	Number	%
<u>TOTAL</u>	3,780	96.7	131	3.3	3,911	100.0
<u>Educational Level</u>						
High School						
Diploma	3,779	100	130	99.2	3,909	99.9
General						
Equivalency						
Diploma	.....	...	...	.....	.....	....
Other	1	...	1	0.8	2	0.1
<u>Mental Category</u>						
I	.....	...	...	.....	.....	....
II	4	0.1	...	....	4	0.1
III-A	285	7.5	8	6.1	293	7.5
III-B	3419	90.4	121	92.4	3540	90.5
IV	72	1.9	2	1.5	74	1.9
<u>Mean ASVAB</u>						
Mechanical	47.5		45.4		47.4	
Administrative	46.6		53.8		46.8	
General	41.8		40.3		41.7	
Electronics	50.7		46.1		50.5	
Composite	186.6		185.6		186.6	

Table 2. Characteristics of Current Standard Accessions

(Pass Current Standard of G45, C170)

	Male		Female		Total	
	Number	%	Number	%	Number	%
<u>Total</u>	49,392	78.8	13,312	21.2	62,704	100.0
<u>Educational Level</u>						
High School Diploma	40,548	82.1	10,784	81.0	51,332	81.9
General Equivalency Diploma	6,049	12.2	2,035	15.3	8,084	12.9
Other	2,795	5.7	493	3.7	3,288	5.2
<u>Mental Category</u>						
I	3,171	6.4	625	4.7	3,796	6.1
II	18,552	37.6	4,434	33.3	22,986	36.6
III-A	18,437	37.3	5,835	43.8	24,272	38.7
III-B	9,219	18.7	2,415	18.1	11,634	18.6
IV	13	....	3	....	16	....
<u>Avg ASVAB</u>						
Mechanical	66.6		36.6		60.2	
Administrative	64.9		74.3		66.9	
General	72.8		72.8		72.8	
Electronics	72.6		60.4		70.0	
Composite	276.9		244.1		269.9	

Table 3. FY79 Attrition Analysis

IMAGE Recruits Only (Pass IMAGE - Fail Current Standard)					
	Male		Female		Total
	Number of Separations	Percent of Enlistments	Number of Separations	Percent of Enlistments	Number of Separations
BMT	214	5.7	19	14.5	233
Technical Training	60	1.6	7	5.3	67
Post Training	47	1.2	1	.8	48
Total	321	8.5	27	20.6	348
					6.0
					1.7
					1.2
					8.9

Current Standard Accessions (Pass Current Standard - Pass & Fail IMAGE)					
	Male		Female		Total
	Number of Separations	Percent of Enlistments	Number of Separations	Percent of Enlistments	Number of Separations
BMT	2,585	5.2	1,329	10.0	3,914
Technical Training	733	1.5	193	1.4	926
Post Training	516	1.0	148	1.1	664
Total	3,834	7.8	1,670	12.5	5,504
					6.2
					1.5
					1.1
					8.8

NOTE: Percentages may not add to 100% due to rounding error.

III. Comparison of IMAGE and LIFE Model Prediction Equations

Model Enhancement

The LIFE model and its theoretical description were presented in detail in Dempsey et al. (1979) and should be referred to for a complete understanding of the model itself. In brief, the model is designed to predict binary dependent variables using a likelihood function estimation technique for which maximum values are derived. As a prototype, the model had several inherent difficulties. It was originally programmed as a demonstration and not as a practical research tool. The model was basically inefficient from both the standpoint of the computer system's central processing unit (CPU) time usage and data handling capability. In addition, the model frequently failed to converge and yield solutions.

As a result, a contract was awarded for enhancing the LIFE model into a fully capable research tool. The contract was divided into four phases. The first phase involved a thorough research of other models which used maximum likelihood techniques to predict dichotomous criteria and also involved a comparison of these techniques with the LIFE model. Any significant differences in approach and ability to predict dichotomous behavior were noted and considered for use in the enhancement of the prototype. During phase II, the contractor examined the major parts of the prototype with a view toward replacing or updating them with new techniques or algorithms. The objective was to reduce CPU time, core usage, and the model's ability to reach a solution. Documentation for the model was done at phase III, while phase IV involved a demonstration of the improved version of the model.

Several groups outside of the United States Government have been using maximum likelihood techniques for some time to predict dichotomous variables. Most of these groups consist of econometricians and the majority of the applications are being made to

econometric prediction problems. A sample of reports written on these applications is contained in the Bibliography to this report. One report in particular was very important in the enhancement of the LIFE model; this publication (Berndt, Hall, Hall, & Hausman, 1974) contained an algorithm for maximization which has been incorporated into the model. The Berndt, Hall, Hall, and Hausman (B.H.H.H.) algorithm is an iterative, maximization technique, which incorporates many of the latest theories of maximization and was designed to conserve both computation time and storage. The algorithm guarantees convergence to a global maximum and never fails to converge. After incorporation of the B.H.H.H. algorithm, running time on the LIFE model was decreased almost 400%. The second important advance in the prototype came about as a result of discussions with Harvard University personnel whose conditional Probit model had many outstanding features for use as a quality research tool. As a result, several additions were made to the LIFE model, including new analytical and reporting features.

Even after enhancement of the LIFE model, it was still unable to handle over 3,000 observations and 12 independent variables. To solve this problem, the model was converted to reading the data into mass storage instead of into a matrix. This modification increased the data holding capability up to 10,000 observations with 20 independent variables and will allow researchers to handle almost any binary prediction problem. However, this specific modification is not necessary for the research scientist who has access to a virtual memory machine. On this type of computer, the matrix can be expanded greatly to meet data requirements without exceeding core limits. The only limit then becomes CPU time available, and the enhanced version of LIFE should make the design of longer problems practical even on a busy machine.

Prediction Equation Development

The prediction equation used in Project IMAGE was developed 3 years ago from a 1972 data base. Although it has been successful, this equation needed to be updated by replacing it with one developed using the LIFE model on a more recent data base. As a result, work was initiated to develop two data base samples taken from the population of 1975 non-prior service (NPS) recruits into the Air Force. Two samples of 3,000 observations each were developed from this population, one for prediction equation development and one for cross-validation. After removing records with missing or invalid ASVAB scores, the prediction development sample contained 2,541 valid cases and the cross-validation sample contained 2,526 cases. In the prediction sample, 744 were discharged from the Air Force within 36 months after enlisting and 839 within 42 months after enlisting. An attempt was made to develop a prediction equation for both criteria to determine the difference in predictive accuracy. These two equations developed using the LIFE model are shown in Table 4. The equations are very similar with only slight variations in the significant variables. The prediction accuracy of the two equations is compared in Tables 5 and 6. These "hit" tables show how well the two equations were able to identify actual successes and failures correctly. The equation developed was more accurate in predicting attritions for the 42-month criterion than for the 36-month criterion (55.4% versus 52.1%). However, the equation was more accurate for predicting successes on the 36-month criterion than on the 42-month criterion (73.4% versus 69.7%). Because the specific purpose of IMAGE would be to waiver a predicted success into the Air Force, and because the 36-month criterion is also the one used by the Office of the Secretary of Defense as the proper measure of attrition, it was used as the criterion of interest in the rest of this study.

Using the 36-month criterion, the next part of the study compared the ability of the original IMAGE equation for predicting success to the ability of a new equation using the LIFE model. In order to make this comparison, cases with missing or invalid AFQT scores were eliminated. This reduced the prediction sample to 2,522 cases and the cross-validation sample to 2,508 cases. It was conjectured that the current IMAGE equation would not predict success well on a new sample for several reasons. First, the IMAGE equation was developed on an all-male sample of 1972 recruits, and the new sample included females. Second, the IMAGE equation predicted success using data from the 1972 sample (means and standard deviations) and these were very different from the data in 1975. In 1972, 86% of the sample were 18 to 26 years old; in 1975, 98% of the sample were in this age group. In order to find a significant change in attrition behavior, this age bracket was decreased to 18 to 23 years old, which still included 92% of the sample. The English indicator changed in a similar fashion. In 1972, 6% of the sample had failed to complete a high school English course; in 1975, only 2% had failed to complete English.

Table 4. Comparison of Coefficients of Prediction Equations

	Means	Coefficient For 36 Months	Coefficient For 42 Months
General	68.7	.004*	.005*
Composite	250.6	-.002*	-.001*
¹ Educational Level	.11	.599*	.624*
² Algebra	.77	-.102	-.103
² Biology	.79	-.015	-.011
² Chemistry	.30	-.122*	-.083
² English	.98	-.107	-.064
² Geometry	.51	-.142*	-.146*
² Physics	.16	.088	-.053
³ Age	.92	.068	.110

³ - 1 if less than 18 or greater than 23, 0 otherwise

² - 1 if taken in high school, 0 otherwise

¹ - 0 if high school graduate or greater, 1 otherwise

*Asymptotic t value significant at .05 level

Table 5. Prediction Accuracy of Equations
42-Month Criterion

Category	Predicted Attritions	Predicted Successes	Total	Percent Correct
Actual Attritions	153	686	839	18.2
Actual Successes	<u>123</u>	<u>1,579</u>	<u>1,702</u>	92.8
Total	276	2,265	2,541	
Percent Correct	55.4	69.7	67.0	

Table 6. Prediction Accuracy of Equations
36-Month Criterion

Category	Predicted Attritions	Predicted Successes	Total	Percent Correct
Actual Attritions	138	606	744	18.5
Actual Successes	<u>127</u>	<u>1,670</u>	<u>1,797</u>	92.9
Total	265	2,276	2,541	
Percent Correct	52.1	73.4	70.7	

Table 7 allows an inspection of the LIFE equation and the IMAGE equation. The AFQT score and the Trigonometry score were not significantly weighted in the LIFE equation and were left out since only 10 variables could be included in the original LIFE Model. The Physics variable did appear in the LIFE equation but not in the IMAGE equation. In addition, magnitudes and signs of the coefficients differed significantly between the two equations. These differences appear to be primarily due to the changes in samples from 1972 to 1975.

A third equation was developed using the expanded data handling version of the LIFE model. This equation included the AFQT variable and the Trigonometry variable, as well as the other 10 variables included in the LIFE prediction equation. This equation is also shown in Table 7. Four different prediction systems were generated for predictive ability comparisons: LIFE model with 10 variables (LIFE equation), LIFE model with 12 variables (LIFE equation with AFQT), IMAGE equation with 1972 means and standard deviations (old equation, old data), and IMAGE equation with 1975 means and standard deviations (old equation, new data). These four predictive systems were compared in two different ways. One way involved classification accuracy in a two-by-two contingency table, and the other a goodness-of-fit with a sum of squares statistic. Table 8 shows the contingency table accuracies for the prediction sample, and Table 9 shows the contingency table accuracies for the cross-validation sample. The four prediction systems were very similar on the prediction sample, with success prediction accuracy ranging from 73.2% to 73.6% and failure prediction accuracy ranging from 49% to 51%. On the cross-validation sample (using the means and standard deviations from the prediction sample for a realistic application) the LIFE equation using AFQT performed better than the other three, but not by a large margin. For the goodness-of-fit test, the actual occurrence (failure or success) was compared to the predictive probability of success, and the squared error was summed over all cases. Table 10 shows the comparison for the four systems and the two samples. There was no significant difference between the four systems on the prediction sample, but on the cross-validation sample there were significant differences. The old equation using the new data was significantly better at predicting the probability of success than the other three. This leads to the observation that the LIFE equation using AFQT will be best suited to the problem of predicting the occurrence of success among airmen, but will not be better than the current IMAGE equation for predicting the probability of this occurrence, using updated means and standard deviations.

Table 7. Comparison of Equations

	IMAGE Coefficient	LIFE Prediction Equation 36-Month Criterion (10 Variables)	LIFE Prediction Equations Using AFQT
General	-.000006	.004	.005
Composite	-.001	-.002	.001
AFQT	-.0009	....	.001
Ed Level	.696	.599	.586
Algebra	-.120	-.102	.113
Biology	-.036	-.015	.008
Chemistry	-.027	-.122	.131
English	-.665	-.107	.131
Geometry	-.101	-.142	.147
Trigonometry	-.074	...	.017
Physics	....	-.088	.080
Age	-.198	.068	.092
Variance	1.065	1.012	1.0

Table 8. Contingency Table Accuracy for Prediction Sample (1975)

	Prediction Accuracy	
	Successes*	Failures**
Old equation, old data	73.3	50.8
Old equation, new data	73.6	49.0
Life equation	73.4	49.3
Life equation, with AFQT	73.2	51.0

*i.e., percentages of predicted successes that were actually successes.

**i.e., percentages of predicted failures that were actually failures.

Table 9. Contingency Table Accuracy for Cross-Validation Sample

	Prediction Accuracy	
	Successes *	Failures **
Old equation, old data	73.5	48.1
Old equation, new data	73.7	47.2
LIFE equation	73.6	47.4
LIFE equation, using AFQT	74.9	49.6

*i.e., percentages of predicted successes that were actually successes.

**i.e., percentages of predicted failures that were actually failures.

Table 10. Comparison of Goodness-of-Fit

	Prediction Sample		Cross-validation Sample	
	SSQ	MSQ	SSQ	MSQ
Old equation, old data	253.50	.10	500.11	.20
Old equation, new data	299.50	.23	373.04	.15
LIFE equation	315.53	.13	514.41	.21
LIFE equation with AFQT	314.65	.12	510.54	.20

IV. CONCLUSIONS

Conclusions

1. Project IMAGE has successfully demonstrated that the goal of increased accessions without increased attrition is achievable, using the prototype LIFE model equation.

2. The enhanced LIFE model prediction equation was capable of more reliable predictions of first term success than was the Project IMAGE equation.

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